Advanced light source technologies that enable high-volume manufacturing of DUV lithography extensions

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1. INTRODUCTION

Extending DUV lithography with double patterning (DP) has gained widespread use at the 32nm technology node. The lithography community has converged now on extending the use of immersion DP lithography to the 22nm node. Since DP involves exposing critical layers twice in order to achieve the necessary feature resolution, it has an adverse impact on the lithography tool productivity. In order to support productivity improvements and the resulting tighter requirements for CD uniformity and overlay for immersion DP lithography, stringent demands are placed on the light source performance.

We introduced the XLR™ 600ix in 2010 at various chipmaker locations and reported on the capability of this light source to operate in the challenging environment presented by immersion DP lithography.[1] Various technology advancements were introduced and the results of the reliability testing were presented.[1] In this paper, the performance of the light source *in the field* is presented, demonstrating the stable and reliable performance.

We have continued to further improve on the reliability, tool availability and performance flexibility of our DUV light sources by developing and implementing newer technology advancements. Specifically, improvements in the discharge chamber gas control and the capability to operate over a wide range of spectral bandwidths were developed. Improved gas control extends gas life thereby improving light source availability. The capability to operate over a wide range of spectral bandwidths for the purposes of increasing depth of focus (DOF) is known as focus drilling, which supports up to 2X improvement in the DOF at the wafer for critical contact and via layers. In this paper, the key elements of these technology advancements are described.

2. PERFORMANCE AT HIGH VOLUME MANUFACTURING SITES

The XLR 600ix light source has been integrated into advanced DP immersion scanners in the market where it has been exploited for its operational flexibility (60W to 90W) while meeting all the necessary performance requirements for energy stability, bandwidth stability and wavelength stability. We have demonstrated the ability to meet the necessary performance requirements without sacrificing product reliability. The introduction and initial characterization results were reported previously[1]. To date, there are more than 100 units supporting high volume production in memory, foundry and logic applications, with an average uptime of 99.8%.

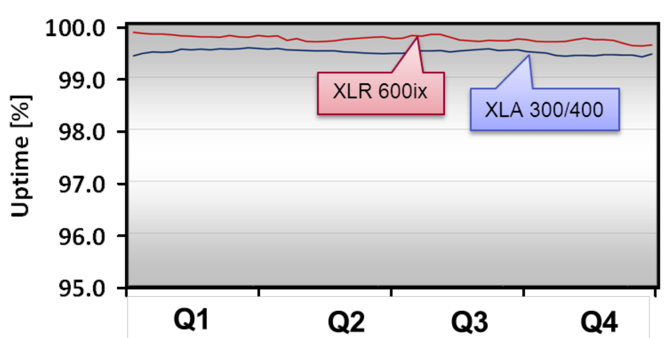

Figure 1: Light source availability reported using supplier dependent uptime for the XLR 600ix during 2011. The XLR 600ix achieved 99.8% uptime at the close of 2011

and is compared to the prior-generation XLA 300/400 family of light source which achieved 99.6% uptime at the close of 2011.

The flexibility to operate over a range of output power from 60W to 90W subjects the light source to stringent performance requirements. For example, operation at 90W requires fewer pulses to achieve the same dose exposure when compared to operating at 60W. The challenging operational condition then for the light source is at 90W output power and at the reduced exposure window sizes. In order to achieve improved dose stability, further refinements were developed in the pulse-to-pulse energy control algorithms that include feed-forward and feedback control. The resultant field performance of the light source at a memory chipmaker fab is shown in figures 2 through 4. The light source was operated at 90W for over a year and has demonstrated stable and predictable performance under such challenging conditions.

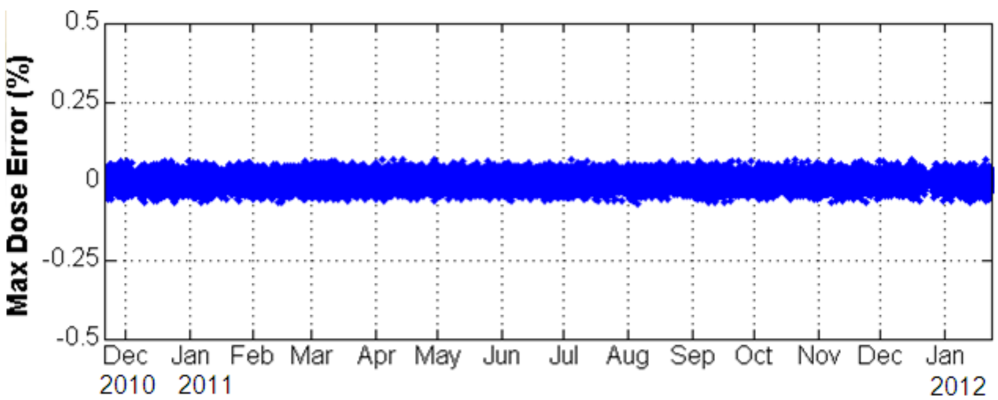

Figure 2: Maximum dose error measured on a light source in 90W operation at a memory fab. Performance is stable and functioning within 0.05% throughout its operation.

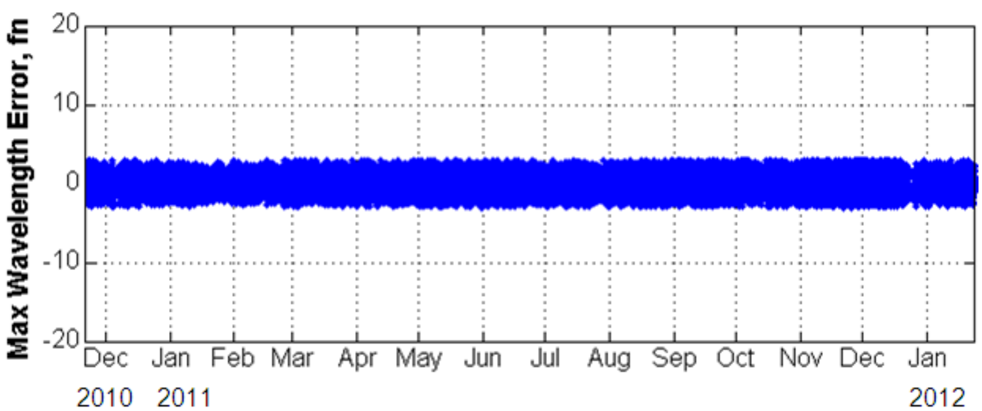

Figure 3: Maximum wavelength error measured on a light source in 90W operation at a memory fab. Performance is stable and functioning within less than 5fm throughout its operation

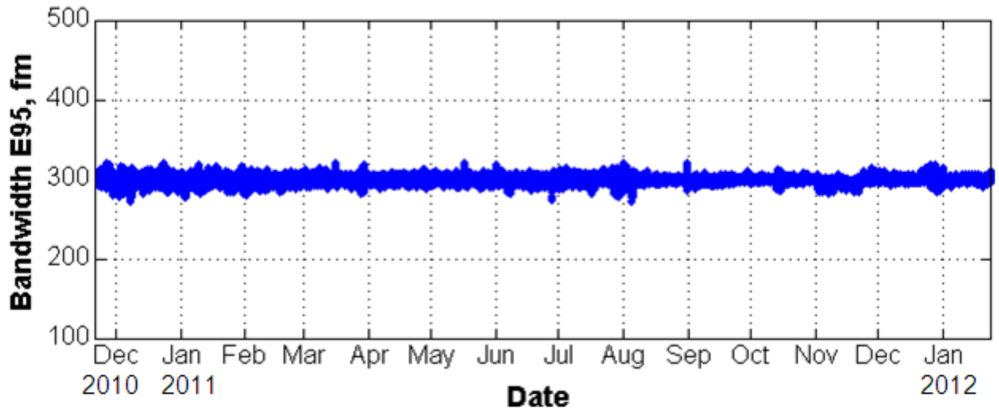

Figure 4: E95 bandwidth measured on a light source in 90W operation at a memory fab. Performance is stable and functioning within less than ± 50fm from nominal throughout its operation.

3. TECHNOLOGY ADVANCEMENTS IN GAS MANAGEMENT

Discharge chamber gas requires a periodic refresh which affects uptime. Recently, we developed further improvements in gas management technology, named iGLX™, to extend gas life, automate gas optimization and reduce the overall chamber gas consumption, all of which directly translates to further improvements to light source uptime.2 With iGLX, discharge chamber gas life is extended to 4Bp from the previous 2Bp capability, which translates to almost 7 weeks time between gas refills assuming a nominal 30 Bp/year pulse usage rate. The resultant performance is illustrated in figure 5, showing stable bandwidth between gas refills

Another key benefit from iGLX gas management technology is the reduced fluorine-mix gas usage. By using advanced model-based techniques, the accuracy and repeatability of chamber gas concentration has been greatly improved. This has resulted in a reduction in fluorine gas-mix usage by ~ 20% over previous gas management technologies. Results from several systems in the field have confirmed benefits in higher availability and lower gas consumption.

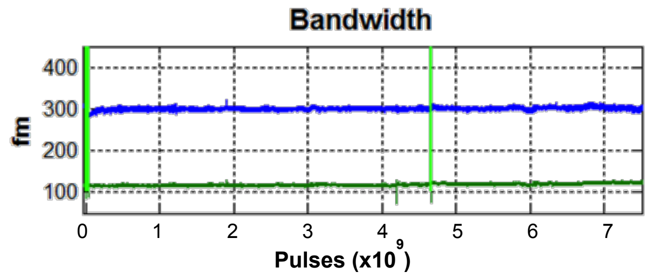

Figure 5: Bandwidth stability during an extended period between gas refills, illustrating iGLX can maintain stable performance with greater than 4Bp between refills. The top data represents E95 bandwidth, while the lower data represents full width half-maximum (FWHM) bandwidth. The vertical bar shows the refill events.

4. TECHNOLOGY ADVANCEMENTS WITH FOCUS DRILLING

Light sources used in advanced photolithography usually require a light source with narrow spectral bandwidth to support achieving the necessary CD uniformity. However, this also limits the process window available to chipmakers in high N.A. systems where the depth of focus (DoF) is small. The challenge for contact layers in particular is the decreasing process window area with reducing feature sizes. We have developed focus drilling technology to support a larger process window in the patterning of contact and via layers.3 The goal is to increase DoF without a significantly adverse impact on critical process parameters like CD uniformity, mask error enhancement factor (MEEF) or exposure latitude (EL). This is enabled by providing a light source with the capability to broaden the spectral bandwidth to suit a specific chipmaker process. The focus drilling feature provides such a broad spectral bandwidth tuning capability along with the necessary supporting metrology and control capability and thereby providing increased process latitude to chipmakers.3

We have investigated many novel methods of spectral tuning.4 Once such embodiment has been integrated into the light source to support three key elements that are needed to support the focus drilling feature. The key elements are bandwidth actuation (tuning), spectral metrology and a control scheme. Novel improvements have been integrated into the line narrowing module (LNM) to provide a wide spectral bandwidth tuning range. This is essential to providing the increased DoF and its associated process latitude. Separately, advanced metrology methods have been incorporated into the bandwidth analysis module (BAM) to support accurate spectral measurements over the wide tuning range. Accurate bandwidth metrology supports chipmaker process repeatability.

The spectral bandwidth tuning range that is available with the new LNM is shown in figure 6 below. Using spectral E95 as the metric, the tuning range that is available with focus drilling is increased to up to 1.8pm. This is supported with advanced bandwidth metrology that can accurately measure various spectral parameters like FWHM, E95 or any other *derived* spectral metric.

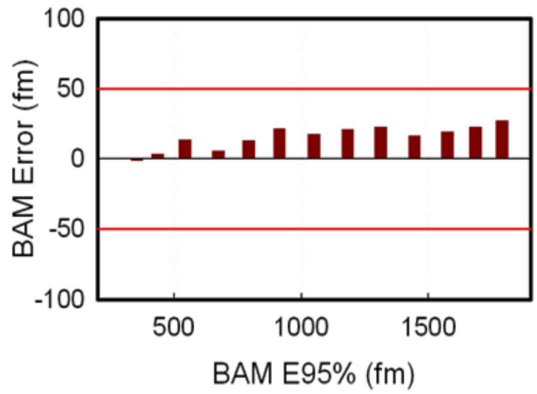

Figure 6: The graph illustrates the accuracy of the on-board metrology and plots the difference between the values measured by the BAM and an external high-resolution grating spectrometer. The red lines represent the accuracy that is required by chipmakers to support the necessary process repeatability.

Once such recently introduced parameter called CBW (Convolved Spectral Width) is also measured by the new BAM. CBW is a spectral metric derived from the convolution of the aerial image function with the light source spectral shape. (See reference 5 for a detailed description of CBW). The essential point here is that any such derived spectral metric can be measured and reported by the metrology module. This advanced bandwidth metrology system uses a sophisticated de-convolution method to quickly and accurately extract the light source spectrum. In addition, control algorithms have been developed to integrate all the feedback to stabilize the bandwidth to the desired target value of any one of the derived bandwidth metrics. Shown in figure 7 below is one such case where the control system is stabilizing the light source to a target CBW value. The control algorithm has a feedback component and a feed-forward component to ensure that the system very quickly and accurately stabilizes to the target value required by the user.

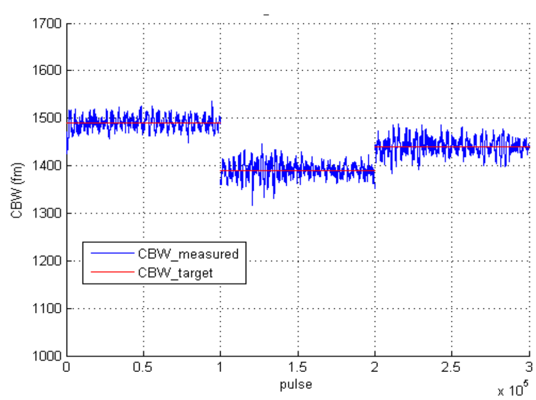

Figure 7: Closed-loop performance of the control system stabilizing the light source spectral bandwidth to the various target values set by the user.

5. CONCLUSIONS

In summary, we have introduced improvements on the latest ArF immersion light source that have consistently demonstrated high performance and reliability in the challenging environment presented by high volume double patterning lithography. Performance expectations from the implementation of various technology advancements have been realized. Fielded systems have demonstrated the ability of the XLR

600ix systems to meet or exceed the productivity requirements over long operation time periods. In addition, we have enabled enhanced process capabilities by developing improved DoF solutions using focus drilling.

6. REFERENCES

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